Initiatives to Address Vehicle Compatibility

National Highway Traffic Safety Administration

June 2003

TABLE OF CONTENTS

I. Introduction

The mission of the National Highway Traffic Safety Administration (NHTSA) is to save lives, prevent injuries and reduce traffic-related health care and other economic costs. The agency develops, promotes and implements effective educational, engineering, and enforcement programs aimed at ending preventable tragedies and reducing the economic costs associated with motor vehicle use and highway travel.

As an integral part of the U.S. Department of Transportation (DOT), the agency improves public health and enhances the quality of transportation by helping to make highway travel safer. A multi-disciplinary approach is used that draws upon diverse fields such as epidemiology, engineering, biomechanics, the social sciences, human factors, economics, education, law enforcement and communication science to address one of the most complex and challenging public health problems facing our society.

NHTSA is the national and international leader in collecting and analyzing motor vehicle crash data, and in developing countermeasures relevant to preventing and mitigating vehicle crashes, thereby reducing and preventing resulting fatalities and traumatic injury. The agency regulates motor vehicle and original equipment manufacturers through its safety standards program; provides national and international leadership in understanding and assessing the safety impact of advanced technologies; sponsors critical research; spurs progress in harmonizing international safety standards; and conducts innovative projects to improve traffic and motor vehicle safety. All aspects of engineering, education, enforcement and evaluation are incorporated into programs to address the challenges of crash and injury prevention involving people, vehicles, and the roadway environment.

The following report presents an in-depth look at one of the most significant safety issues impacting highway safety and the success of NHTSA's mission – vehicle compatibility. This document describes the safety problem represented by vehicle incompatibility and provides strategies the agency plans to pursue in improving vehicle compatibility, thereby saving lives. In addition to the full agenda of highway safety issues, impaired driving, rollover mitigation and safety belt use are the other priority issues set by NHTSA to reduce the occurrence and consequences of motor vehicle fatalities and injuries. The agency is offering the public the opportunity to comment on each of the four documents, which can be found at future dates on NHTSA's Web site at http://www.nhtsa.dot.gov/people/iptreports.html and also on DOT's docket management system (DMS) at http://dms.dot.gov/. The docket numbers for each of the respective reports are as follows:

- Safety Belt Use NHTSA-2003-14620;
- Impaired Driving NHTSA-2003-14621;
- Rollover Mitigation NHTSA-2003-14622; and,
- Vehicle Compatibility NHTSA-2003-14623.

II. Highway Safety Overview

Despite significant gains since the enactment of Federal motor vehicle and highway safety legislation in the mid 1960's, the annual toll of traffic crashes remains tragically high. In 2001, 42,116 people were killed on the Nation's highways and an additional 3.03 million people suffered serious injuries. Motor vehicle crashes are the leading cause of death and disability for Americans between the ages of 2 and 33.

Traffic crashes are not only a grave public health problem for our Nation, but also a significant economic burden. Traffic crashes cost our economy approximately $230 billion in 2000, or 2.3 percent of the U.S. Gross Domestic Product. This translates to an annual average of $820 for every person living in the United States. Included in this figure is $81 billion in lost productivity, $32.6 billion in medical expenses, and $59 billion in property damage. The average cost for a critically injured survivor of a motor vehicle crash is estimated at $1.1 million over a lifetime. This figure does not even begin to reflect the physical and psychological suffering of the victims and their families.

III. Integrated Project Team Formation

In September 2002, NHTSA formed four integrated project teams (IPTs) to conduct an in-depth review of four priority areas:

- Safety Belt Use,
- Impaired Driving,
- Rollover Mitigation, and,
- Vehicle Compatibility.

These teams were chartered to support the Agency's strategic planning work by using comprehensive, science and evidence-based analyses to identify innovative solutions and recommend effective strategies in their respective issue areas. The Federal Highway Administration (FHWA), another DOT agency, who has lead responsibility along with State highway agencies for initiatives relating to roadway and roadside hardware improvements, had representatives on the rollover mitigation and vehicle compatibility teams.

Teams were encouraged to be innovative in their thinking and novel in their approaches. The resulting proposals covered a wide range of possible solutions, from what could be accomplished through changing driver behavior, to vehicle modifications and roadway improvements. Recommended strategies were based on science, data and other available evidence. The teams also attempted to estimate the possible benefits and costs associated with implementing various strategies.

Each team began by conducting a problem identification analysis – researching and analyzing crash data in the problem area (e.g., number of injuries and fatalities associated with each issue). The purpose of the problem identification was to accurately describe the safety problem in enough depth to provide structure and underpinning to various potential strategies.

The teams then organized and linked the array of possible strategies to their potential safety impacts. This included estimating the benefits and timeframe for implementation, discussing risks and uncertainties, and identifying constraints.

In February 2003, NHTSA senior management officials evaluated the IPT strategies to determine which strategies the agency should pursue. The recommended strategies presented here are not simply a list of activities but relate in a strategic and interdependent manner and, if implemented effectively, will lead to improved safety performance. Each of the four priorities – safety belt use, impaired driving, rollover mitigation and vehicle compatibility – is addressed in a separate document. This document reflects the agency's plan for vehicle compatibility strategies.

IV. General Problem Identification for Vehicle Compatibility

Since before the advent of the horseless carriage, traffic safety planners have been confronted with the challenge of providing safe transportation while accommodating a wide variety of transportation modes. Some of this has been accomplished by having special infrastructures, such as rails for trains and sidewalks for pedestrians. However, a wide variety of vehicles, including commercial vehicles, motorcycles, small and large automobiles, etc. use the roadways. In its broadest sense, vehicle compatibility can be defined as the ability to create conditions making roads, roadside hardware, and vehicles well matched to safely transport motorists.

Compatibility encompasses human behavior, crash avoidance, and crashworthiness components. Before a crash, behavioral issues and crash avoidance factors, such as not impairing visibility or causing glare for drivers of other vehicles, lead to incompatibilities among vehicles. During a vehicle collision, compatibility is determined by the energy management and encompassed by the relative mass, geometry, and structural stiffness characteristics of the collision partners.

NHTSA has been concerned with vehicle compatibility in crashes since the agency was established. Over twenty-five years ago, NHTSA conducted studies on vehicle aggressiveness (injury risk vehicles pose to drivers of other vehicles with which they collide) and methods for measuring it. At the Fifteenth International Conference on the Enhanced Safety of Vehicles (ESV) held in Melbourne, Australia, May 1996, an International Harmonization Research Activity (IHRA) working group on vehicle compatibility was established and has since been exploring methodologies to assess it. In 1998, prompted by the growth in light trucks and vans (LTVs), including sport utility vehicles (SUVs), NHTSA published an overview of vehicle compatibility and LTV issues.[1] Over the past several years, NHTSA has published a number of papers describing the research that has been conducted on vehicle compatibility. In March 2002, vehicle compatibility was included as an area of focus for the exchange of information in the program of work adopted under the World Forum for the Harmonization of Vehicle Regulations (WP.29) 1998 Global Agreement. Most recently, in the Fall of 2002, NHTSA renewed a bilateral agreement with Canada and signed a new bilateral agreement with Japan, under which there will be the exchange of ideas on best regulatory approaches in the area of vehicle compatibility, including the possibility of conducting joint research and testing.

NHTSA has also been concerned about headlight glare. In recent years, one of the major areas of consumer complaints regarding glare has been high-mounted headlights on LTVs. Headlight glare from LTVs appears to increase stress for other drivers, particularly at night. On September 28, 2001, NHTSA published a request for comments on glare produced by lamps mounted on the front of vehicles, including upper and lower headlamps, and auxiliary lower beam headlamps. To date, the agency had received over 4,000 comments, mostly from ordinary citizens requesting initiatives to reduce glare.

Likewise, FHWA has similar concerns with the evolution of vehicle structural designs and the emergence of new vehicle platforms, and raises questions concerning the compatibility of the vehicle fleet with existing roadside hardware systems (e.g., guardrails). Changes in vehicle attributes, including size, mass, and geometry, have been considerable, while design criteria for roadside features have remained virtually unchanged. The roadside features designed many decades ago to perform optimally with older vehicles cannot be expected to perform as well with newer vehicles.

The following sections provide compatibility background information and problem definition in terms of trends over time, occupant fatalities, and driver fatality risk.

1. Background

Vehicle compatibility has been a long time concern of safety researchers, including those at NHTSA. The roots of the government's effort can be traced to the international experimental safety vehicle program that was underway during the 1970s. As part of Renault's development effort in the program, Chillon published a paper in 1971 to examine the effect of a vehicle's aggressiveness in side crashes.[2] In the agency's own program, Kossar examined the compatibility of large and small car crashes in a paper published in 1974.[3] Ford Motor Company initiated the development of a system methodology for optimizing its experimental safety vehicle's characteristics in order to minimize the injuries experienced not only by the vehicle's occupants but those of the entire fleet.[4]

In its Five Year Plan published in March 1978, NHTSA explored rulemaking to increase occupant protection in all crash modes.[5] One important consideration in this exploratory rulemaking was to understand and control vehicle aggressiveness. MacLaughlin, Saul, et al. analyzed a series of crash tests conducted by the agency to identify structural parameters contributing to vehicle aggressiveness in frontal collisions between large and small cars. As part of this study, computer modeling was used to statistically determine the significance of specific vehicle parameters on aggressiveness. Also, the capability of different types of barriers to measure aggressiveness was evaluated.[6,7,8]

During the 1980s, the agency expanded its efforts in examining compatibility as part of its side impact research program. Monk and Willke published their results and analyses from a series of side impact crash tests which utilized altered Moving Deformable Barrier (MDB) honeycomb faces (i.e., lowered bumper, lowered stiffness, lowered hood profile) to examine such changes on the outcome of the dummy measures in the struck vehicle, a

Volkswagen Rabbit.[9,10] In these tests, it was found that lowering the hood profile provided the greatest reduction in injury risk to occupants of the struck vehicle.[*]

The genesis of the agency's current program was the Gabler and Hollowell reformulation of the Ford methodology designed to optimize the characteristics of all of the vehicles representing the entire fleet so as to further improve overall safety.[11] In examining the safety problem as part of their effort to validate the approach, Hollowell and Gabler investigated the problem of vehicle aggressivity in two-vehicle traffic crashes.[12] Using the other vehicle fatalities per registered subject vehicle as a measure of a vehicle's aggressivity, the examination of U.S. crash statistics showed a striking incompatibility between LTVs' and passenger cars' crash performance. As measured by this aggressivity metric, LTVs as a class were found to be twice as aggressive as passenger cars. This mismatch in crash performance has considerable consequences for the traffic safety environment as approximately half of all passenger vehicles sold in the U.S. are LTVs.

The areas of roadside hardware and glare have not received as much attention in previous research, in part because of difficulties in collecting data. In response, this document includes initiatives for improved data collection regarding roadside hardware and new research programs for headlight glare.

2. Problem Definition

NHTSA has published papers that describe the growing compatibility problem in the U.S. fleet.[13,14] This section provides an update of these previous reports by examining changes in the vehicle fleet and occupant fatality patterns, by using data from the most recent Fatality Analysis Reporting System (2001 FARS) to determine the scope of various aspects of the compatibility problem, and by presenting recent estimates of driver fatality risk based on the types of vehicles involved.

Following agency conventions, large vehicles have a GVWR greater than 10,000 pounds and include buses, large vans, straight trucks, and truck-tractors. Light vehicles have a gross vehicle weight rating (GVWR) of 10,000 pounds or less and include passenger cars (defined as automobiles and auto-based vehicles) and LTVs (defined as utility vehicles, small vans, and pickup trucks). As shown in **Figure 1**, the sales and registrations of LTVs as a percentage of the light vehicle fleet have steadily increased since 1984.[15,16] In fact, sales of LTVs reached 50 percent of all light vehicles sold in 2001.

[*] In the 1980's, FHWA also conducted highway-related compatibility research to collect additional data for barrier crashes. Relevant information for a limited population of roadside events was identified. However, the extensive amount of data collection and associated high costs led to the eventual termination of the study.

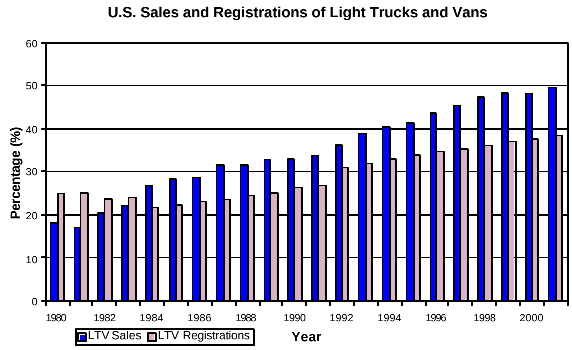

Figure 1 -- LTV sales and registration

The increasing number of LTVs on the road is leading to an increasing number of fatalities for passenger car occupants who are in collisions with LTVs. **Figure 2** demonstrates this change over time by comparing the percentages of occupant fatalities in two-vehicle crashes by whether the collision involved two cars, two LTVs, or a car and an LTV. The percentages are based on the 1980 through 2001 FARS, which are censuses of all crashes involving a motor vehicle on a public roadway that resulted in at least one fatality within 30 days of the incident. The number of fatalities from collisions between a car and an LTV demonstrates a strong upward trend starting in 1983 and tracks the trends in LTV sales and registration. This increase in LTV sales has important implications for roadside hardware and glare initiatives. Because LTVs will be an increasing proportion of future vehicle fleets, roadside hardware will interact with an increasingly diverse set of vehicles. The increase in LTV sales also suggests that car drivers will have more exposure to LTV lighting systems, which tend to have a higher mounting height.

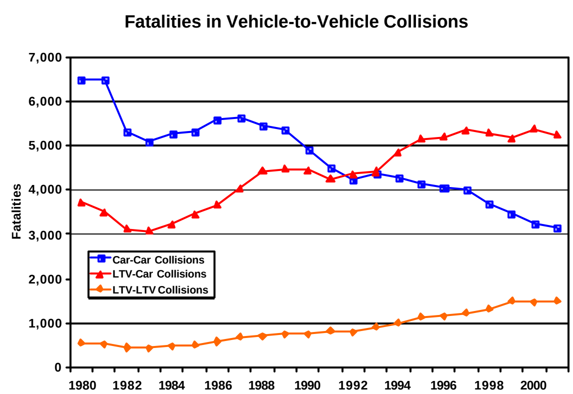

Figure 2 -- Occupant fatalities in 2-vehicle crashes

While **Figure 2** focused on vehicle compatibility, NHTSA's definition of compatibility reflects the wide range of potentially affected populations. The purpose of this problem definition assessment is twofold. The first is to determine the scope of various aspects of the compatibility problem; the second is to provide estimates of affected populations for planning purposes. The analysis focuses on fatalities for determining target populations and is based on the most recent FARS (2001). FARS does contain information on non-motorist fatalities, but this analysis focuses on vehicle occupant deaths.

Table 1 provides a breakdown of vehicle occupant fatalities from the 2001 FARS. The table contains two sets of figures that relate fatalities to vehicle type and the number of vehicles involved. The first set is the number and percent of all fatalities. The second set lists the number and percent of fatally injured occupants who were properly using a safety belt in crashes that did not involve alcohol. The belted-no alcohol subset provides a comparison of all fatalities to a subset of fatalities to determine the scope of the problem in relatively safe situations. While the patterns in both sets of fatalities were examined, this target safety assessment focuses on all fatalities. The role of alcohol-impaired driving and the failure to use safety belts in explaining traffic fatalities is better addressed by NHTSA's companion impaired driving and safety belt use IPT reports.

Table 1: Vehicle Occupant Fatalities
by Vehicle Type and Number of Vehicles Involved (2001 FARS)

	All Fatalities	Percent of All Fatalities	Belted Fatalities with No Alcohol Involvement
Light Vehicle Occupant			
Single Vehicle (see Table 2)	15,490	43	2,456
Two Vehicles (see Table 3)	13,673	38	4,874
Three or More Vehicles	2,762	8	1,086
Subtotal	*31,925*	*88*	*8,416*
Large Vehicle Occupant			
Single Vehicle (see Table 2)	497	1	88
Two Vehicles (see Table 3)	190	1	52
Three or More Vehicles	71	<1	15
Subtotal	*758*	*2*	*155*
Motorcycle Occupant	*3,181*	*9*	
Other/Unknown Vehicle Occupant	*522*	*1*	*7*
Vehicle Occupant Total	36,386	100%	8,578

There were 36,386 motor vehicle occupant fatalities recorded in 2001. (The overall highway fatality number, which amounted to 42,116, includes non-occupants such as pedestrians and bicyclists.) The overwhelming majority of occupant fatalities occur in light vehicles, and the most frequent situation is a single light vehicle crash (43 percent of fatalities). Once unbelted fatalities and fatalities from alcohol-related crashes are removed from the total, the number of fatalities drops to 8,578. This drop reflects the significant number of deaths attributed to alcohol and a lack of restraint use, as well as the exclusion of motorcyclists for whom belt use is not relevant. However, it is apparent that a significant number of fatalities still occur even when occupants use restraints and drivers are not impaired.

Table 2 analyzes the first harmful event for the 15,987 fatalities in single-vehicle crashes involving 15,490 light vehicle and 497 large vehicles occupant fatalities from the 2001 FARS. The table demonstrates that a collision with roadside hardware such as a telephone pole or a guardrail is the first harmful event for 3,211 light vehicle and 155 large vehicle occupant fatalities. Collisions with roadside hardware account for a significant number of single-vehicle fatalities. The numbers for light vehicle occupant fatalities in single-vehicle crashes are similar to those where a rollover is the first harmful event, and collisions with roadside hardware account for about one-third of the fatalities to large vehicle occupants in fixed object collisions. The other common fixed objects include trees (3,107 light vehicle occupant fatalities), embankments (1,195 fatalities), and culverts, curbs, and ditches (1,987 fatalities).

Table 2: Light and Large Vehicle Occupant Fatalities in Single-Vehicle Crashes by First Harmful Event (FARS 2001)

	All Fatalities	Percent of All Fatalities
Light Vehicle Occupant		
Overturn	3,572	23
Collision w/ Roadside Hardware	**3,211**	**21**
Collision w/ Other Fixed Object	7,569	49
Other or Unknown	1,138	7
Total Light Vehicle Occupant	15,490	100%
Large Vehicle Occupant		
Overturn	157	32
Collision w/Roadside Hardware	**155**	**31**
Collision w/ Other Fixed Object	108	22
Other or Unknown	77	15
Total Large Vehicle Occupant	497	100%

Table 3 provides a breakdown of the 13,673 light vehicle and 190 large vehicle occupant fatalities in two-vehicle crashes according to whether the occupant's vehicle type and the other vehicle were light or large. Almost three-quarters of the light vehicle occupant fatalities in two-vehicle crashes occur in a collision with another light vehicle, and the other quarter occur in collisions with a large vehicle. For large vehicle occupants, a majority of the fatalities occur in crashes with another large vehicle. This table also demonstrates that for collisions involving one light vehicle and one large vehicle, there are 3,102 light vehicle fatalities compared to 69 large vehicle fatalities.

Table 3: Light and Large Vehicle Occupant Fatalities in Two-Vehicle Crashes by Occupant's Vehicle and Other Vehicle (FARS 2001)

	All Fatalities	Percent of All Fatalities
Light Vehicle Occupant		
Collision w/ Other Light Vehicle	10,440	76
Collision w/ Large Vehicle	3,102	23
Collision w/ Other or Unknown	131	1
Total Light Vehicle Occupant (See Table 4)	13,673	100%
Large Vehicle Occupant		
Collision w/ Light Vehicle	69	36
Collision w/ Other Large Vehicle	116	61
Collision w/ Other or Unknown	5	3
Total Large Vehicle Occupant	190	100%

As **Tables 1** and **3** demonstrate, light vehicle fatalities far outnumber large vehicle fatalities. Therefore, the remaining analysis of the target population focuses on light vehicle occupants. **Table 4** shows the relationship between fatalities and the type of crash for light vehicle occupants. NHTSA defined the type of crash by whether the other vehicle was light or large, the initial point of impact for both vehicles, and whether the occupant's vehicle was striking or struck. The agency used the standard clock position from FARS to summarize the initial point of impact: front if 11, 12, or 1; side if 2, 3, 4, 8, 9, or 10; rear if 5, 6, or 7. It also determined striking or struck using the initial points of impact. Following agency convention, the initial point of impact is not used for crashes involving a rollover.

Table 4: Light Vehicle Occupant Fatalities in Two-Vehicle Crashes by Crash Scenario (FARS 2001)

	All Fatalities	Percent of All Fatalities
Collision w/ Other Light Vehicle		
Front to Front		
Car and Car	1326	10
LTV and Car	1740	13
LTV and LTV	649	5
Front to Side		
Car strikes Car	1335	10
Car strikes LTV	324	2
LTV strikes Car	2076	15
LTV strikes LTV	416	3
Front to Rear		
Car strikes Car	214	2
Car strikes LTV	122	1
LTV strikes Car	197	1
LTV strikes LTV	87	1
Other Situations	230	2
Collisions w/ Large Vehicle		
Front to Front	880	6
Front to Side		
Light strikes large	333	2
Large strikes light	839	6
Front to Rear		
Light strikes large	418	3
Large strikes light	137	1
Other Situations	103	1
Rollover Crashes	2116	15
Collisions w/ Other/Unknown	131	1
Total	13,673	100%

For all light vehicle occupant fatalities in two-vehicle collisions, crashes where at least one vehicle overturned account for 15 percent of the fatalities. However, these rollover collisions are not addressed here because the role of rollovers in explaining traffic fatalities is better addressed by NHTSA's companion rollover mitigation IPT report. Four non-rollover crash scenarios account for 48 percent of the total fatalities. Ranked in descending order of frequency, these four scenarios are as follows: the front of an LTV striking the side of a car, a frontal collision between an LTV and a car, the front of a car striking the side of a car, and a frontal collision between two cars.

Table 4 demonstrates that collisions involving a LTV and a car are the most common two-vehicle crash scenarios in terms of light vehicle occupant fatalities (see also **Figure 2**). One reason that frontal and side crashes involving a LTV and a car produces more fatalities than similar collisions involving two cars may be that the occupant fatality risk is larger for car occupants hit by a LTV than by another car. **Table 5** provides more detailed target population estimates by dividing the light vehicle fatalities for each crash scenario involving two light vehicles into car and LTV occupants. In frontal crashes involving a car and a LTV, there are almost 1,000 more fatalities in the cars than in the LTVs. In side impact crashes involving two cars, there are almost 1,000 more fatalities in the struck than striking vehicle. However, in the case of cars struck in the side by LTVs, there are almost 2,000 more fatalities in the struck cars than the striking LTVs.

Table 5: Light Vehicle Occupant Fatalities in Two-Light Vehicle Crashes by Crash Scenario (FARS 2001)

Front to Front	Car Occupant	LTV Occupant	Driver Fatality Ratio (1^{st} versus 2^{nd} vehicle type)
Car-Car	1,326		
Car-LTV	1,365	375	3.9:1
LTV-LTV		649	
Front to Side	**Striking Occupant**	**Struck Occupant**	
Car strikes Car	172	1,163	1:8.4
Car strikes LTV	156	168	1:1.0
LTV strikes Car	68	2,008	1:28.7
LTV strikes LTV	59	357	1:6.3
Front to Rear	**Striking Occupant**	**Struck Occupant**	
Car strikes Car	78	136	1:1.5
Car strikes LTV	93	29	3.4:1
LTV strikes Car	24	173	1:5.3
LTV strikes LTV	43	44	1.2:1

Table 5 also provides driver fatality ratios. The driver fatality ratio is derived by comparing the number of driver fatalities in the first listed vehicle type with the number in the second listed vehicle type from the 2001 FARS. The focus on driver instead of occupant fatality controls for the fact that cars and LTVs may tend to carry different numbers of passengers. The table shows the scope of one important aspect of the compatibility problem for light vehicle occupants in two-vehicle planar crashes. In frontal collisions involving a car and an LTV, there are almost four times the number of driver fatalities in the car than in the LTV. These numbers suggest that the fatality risk in a car-LTV frontal crash is four times higher for the car driver than the LTV driver. The results are even more dramatic for side impact crashes. The driver in a car struck in the side by another car has an eight times greater fatality risk than the driver in the striking

car. However, the driver fatality risk for the struck car is twenty-nine times greater than the fatality risk for the driver of the striking LTV. Driver fatality ratios were also computed using the subset of fatally injured occupants who were properly using a safety belt in crashes that did not involve alcohol (see **Table 1**). In all scenarios involving a collision between a car and an LTV, the fatality risk for the belted car occupant relative to the belted LTV occupant in non-alcohol crashes was similar to or higher than the car occupant fatality risk reported in **Table 5,** based on all fatalities.

These numbers are descriptive and do not account for factors other than vehicle type, such as driver characteristics, that may also explain the distribution of fatalities. One method of controlling for potentially important confounding factors is to limit the sample to cases that occur under similar circumstances, particularly with regard to the age of the vehicle and the driver's age. Therefore, a second set of fatality ratios were computed only for two-vehicle crashes where both vehicles were model year (MY) 1990 or newer and both drivers were between ages 26 to 55, inclusive. It also would be desirable to examine the compatibility between specific vehicle categories, e.g., SUV into car versus van into car. However, due to data limitations, one year of FARS does not produce enough cases for a meaningful analysis. This second set of driver fatality ratios restricts the sample based on vehicle and driver age but includes the most recent seven years of FARS (1995 to 2001).

Figure 3 shows this set of driver fatality ratios for all passenger cars struck in the front by five LTV vehicle categories based upon the 1995 to 2001 FARS. In all five categories, the driver fatality risk for the car driver is greater than that of the LTV driver. The results also are consistent with the 2001 FARS estimate of the overall car to LTV driver fatality ratio for all LTVs, which was about four.

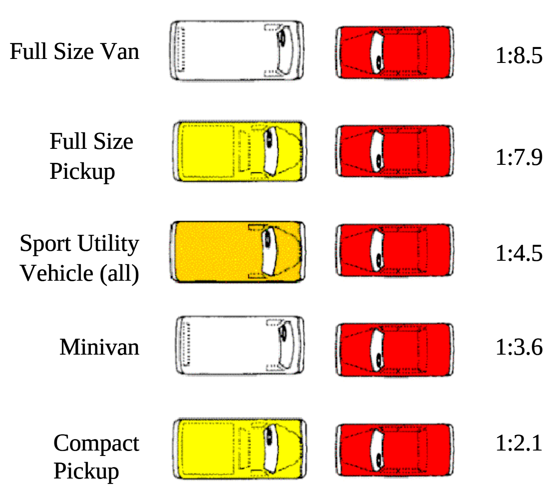

Figure 3 -- Driver fatality ratios for front-to-front LTV-to-car crashes

Driver fatality ratios based upon the 1995 to 2001 FARS were similarly computed for side impact crashes, as shown in **Figure 4**. In side impact crashes, the drivers of the struck vehicles are much more likely to be killed than the drivers of the striking vehicles. In a frontal passenger car to passenger car crash, the driver fatality ratio is about 1:1.

However, in side crashes, the risk for the struck car driver is substantially higher. Therefore, it is important to remember that the 8.2 passenger car fatality ratio is the appropriate baseline for comparing the LTV-into-car fatality ratios. The side impact driver fatality ratios are somewhat unreliable because of the sample size. The large pickup ratio is based on only 8 striking driver fatalities, and the SUVs ratio is based on 10 striking driver fatalities. The passenger car fatality ratio is based on 43 striking driver fatalities. The other vehicle categories had even fewer driver fatalities and were not included in this analysis. Once again these numbers are consistent with the numbers produced using all fatalities from the 2001 FARS.

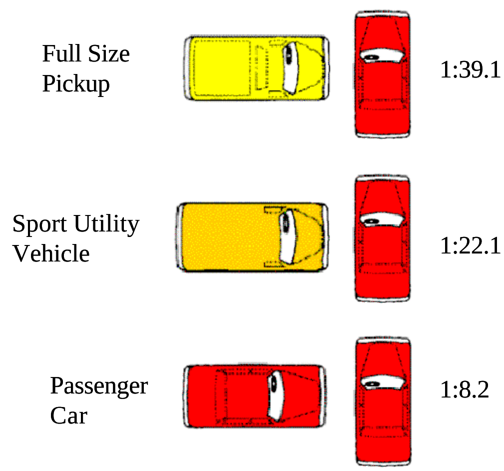

Figure 4 -- Driver fatality ratios for side impact crashes into passenger cars

This section demonstrates why vehicle compatibility continues to be a significant concern for occupant safety in the U.S. fleet. The following points summarize and highlight the problem:

- More LTVs on road increase car driver exposure to LTV lighting systems
  - Over 4,000 public comments regarding glare
- Roadside hardware will interact with an increasingly diverse fleet
  - Over 3,300 fatalities from single-vehicle collisions with roadside hardware
- Increased exposure for car occupants to collisions with LTVs
  - LTV are 50 percent of all light vehicles sold in 2001.
- Large and growing fatalities in car and LTV collisions
  - LTVs striking cars in the side or in a frontal collision account for over 25 percent of light vehicle occupant fatalities in 2-vehicle crashes.
- Greater fatality risk for the car driver than the LTV driver
  - Fatality ratio 340 percent higher for car struck by LTV than another car

V. Proposed Initiatives

The initiatives being pursued in addressing vehicle compatibility are described in this section. NHTSA has the lead on initiatives involving the vehicle, while FHWA has the lead on strategies dealing with roadway strategies. Consumer information efforts are also being pursued by both agencies.

A) Vehicle Strategies

Partner protection, self protection, lighting/glare efforts and the reform of the Corporate Average Fuel Economy (CAFE) program, are included in the vehicle initiatives, and are described in this section. NHTSA is also working with experts in the appropriate United Nations (U.N.) Working Parties, including Passive Safety and Lighting and Light Signaling, to share ideas and research on these issues.

1) Partner Protection

Partner protection involves vehicle design attributes that function to maximize protection of the occupants within the collision partner (struck) vehicle. Or, in terms of vehicle aggressiveness, partner protection can be described as being less aggressive when striking another vehicle.

a) Highlights of Current Program

As noted in Section IV, NHTSA has conducted several analyses to retrospectively determine the aggressiveness of various vehicle classifications for both frontal and side impact collisions. More recently, the agency has initiated efforts to investigate vehicle frontal geometric and stiffness characteristics as measured by the fixed rigid barrier load cells used in conducting frontal NCAP and other agency crash tests, and examined correlations between those vehicle characteristics and the vehicle's aggressiveness metric.

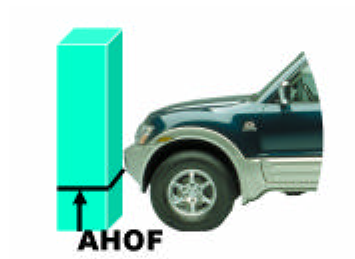

Figure 5 – Illustration of AHOF.

NHTSA has collected impact force data from over 400 NCAP tests to date. In analyzing this data, one of the parameters that emerged as a metric of increased aggressivity in vehicle-to-vehicle crashes is Average Height of Force (AHOF). The AHOF is a single *height measurement* that represents the average height at which a vehicle transfers force to the rigid barrier (**Figure 5**). NHTSA has computed the AHOF for NCAP crash tests predominantly from MY 1982 to the present and has demonstrated the real world significance of the AHOF parameter. Kahane[17] found that the difference in the AHOF between the struck and the striking vehicles had a statistically significant correlation with the fatality risk of a car driver struck on the driver's side by the front of a LTV,[*] possibly because of the seating heights tend to change as AHOF in struck vehicles change.

Various vehicle energy management characteristic parameters, such as initial stiffness and stiffness distribution, have also been developed and analyzed using the load cell data described above. NHTSA has computed the initial stiffness of vehicles for NCAP crash tests predominantly from MY 1981 to the present and has demonstrated that this parameter also has real world significance in terms of vehicle aggressivity.[19] The initial stiffness of an LTV was found to have a statistically significant correlation with the fatality risk to a passenger car driver struck in the front. Stiffness of a

[*] Since side sill height of cars was not routinely measured prior to 1997, AHOF was used as a surrogate for side ground clearance and ride height.

striking car in a left side impact also had a statistically significant correlation with the fatality risk of the struck car's driver.

In addition to these studies, NHTSA also has been conducting crash testing and computer simulation efforts in conjunction with the International Harmonization Research Activities (IHRA) for compatibility.[18,19]

b) *Proposed Initiatives*

Although the analyses and studies conducted to date have retrospectively demonstrated several vehicle characteristics that appear to have considerable promise for establishing compatibility requirements, the agency has yet to demonstrate that any of these characteristics can prospectively be measured in a vehicle crash test, and the level of compatibility quantified. The agency will take the following steps to measure and quantify these characteristics.

1) NHTSA will pursue a comprehensive crash test program in an effort to determine whether vehicles of comparable mass, but with considerably differing characteristics (e.g., AHOF, initial stiffness, etc.), produce quantifiable injury measurement differences for occupants in the struck vehicle.
2) Using existing fixed rigid barrier crash test data, pairs of vehicles that are comparable in classification (e.g., large SUV), but different in a measured characteristic (e.g., high vs. low AHOF) will be identified.
3) Vehicle-to-vehicle crash tests will then be conducted with these vehicle pairs in several configurations to determine whether or not the vehicle characteristic differences have any influence in the struck vehicle occupant injury outcome.
4) If differences can be quantified, NHTSA will seek to identify countermeasures for potential establishment of compatibility requirements.

The agency expects to complete this testing and analysis within one year, and then make a determination on whether or not there is a sufficient basis to initiate a rulemaking effort.

The comprehensive crash test program is based upon utilization of existing fixed rigid load cell barrier testing. NHTSA is pursuing refinement of the measurements through development of a higher resolution load cell barrier that has been evaluated in the IHRA compatibility working group. NHTSA is also examining the efficacy of utilizing a deformable face on the fixed rigid load cell barrier in order to evaluate metrics used to quantify the crash force load distribution. There has been considerable effort by the IHRA and others to evaluate the ability of several different barrier types (e.g., fixed rigid, deformable, moving deformable, progressively deformable, etc.) to measure vehicle aggressiveness, and establish vehicle performance requirements to assure a certain level of compatibility by means of overall energy management. NHTSA believes this is a longer-range effort since barrier characteristics (e.g., mass, stiffness, geometry, etc.) must first be established prior to initiation of a program to establish the efficacy of the selected barrier to assess compatibility and aggressiveness. However, it will continue these efforts in conjunction with the IHRA.

c) Expected Program Outcomes

An expected outcome of this initiative would be to establish a more uniform range of vehicle characteristics within the vehicle fleet. For example, establishing a range (or ranges) for AHOF would lead to improved structural engagement in frontal impacts and would facilitate the design of self protection countermeasures (such as side door beam designs). It may also facilitate improved compatibility with roadside hardware (i.e., guardrails).

Improved energy management between striking and struck vehicles in real world crashes, particularly between passenger cars and LTVs, would be a desired outcome for the longer-range effort. An energy management approach could lead to improved energy sharing in vehicle-to-vehicle crashes. It could also provide the opportunity to improve occupant compartment integrity, thereby decreasing intrusion-related fatalities and injuries and improving partner protection.

2) Self Protection

Self protection is the ability to protect the occupants within the striking vehicle. Most, if not all, of NHTSA's crashworthiness regulations are directed toward evaluating a vehicle's "self protection," or how the vehicle protects its own occupants. For example, Federal Motor Vehicle Safety Standard (FMVSS) No. 208, Occupant Crash Protection, establishes performance requirements for vehicle occupants in frontal crashes, FMVSS No. 214, Side Impact Protection, establishes requirements for side impact crashes, FMVSS No. 301, Fuel System Integrity, provides standards for multiple impact directions, including side and rear, and FMVSS No. 202, Head Restraints, reduces the frequency and severity of neck injury in rear-end and other collisions.

FMVSS No. 208 has been significantly upgraded in the past few years with incorporation of advanced air bag requirements. Notices of Proposed Rulemaking for FMVSS No. 301 and FMVSS No. 202 have been issued, with final rules to be published in the near future. However, FMVSS No. 214 has not been substantially upgraded in over a decade, and as shown in Section IV, fatality ratios for LTV-to-car side impact collisions are considerably greater for this collision configuration. Consequently, the self-protection initiatives related to compatibility in this report are focused on side impact protection upgrades.

a) Highlights of Current Program

NHTSA has conducted vehicle-to-pole and vehicle-to-vehicle crash tests showing that side impact air bags and/or inflatable curtains can improve a struck vehicle's self protection by absorbing some of the impact energy and providing head and chest protection.[20, 21] (**Figure 6**) While all vehicles are vulnerable to impacts with rigid narrow objects, the agency believes similar self-protection countermeasures would also benefit smaller passenger car occupants when they are struck

Figure 6 -- Side impact pole test

by high-riding LTVs. In these crashes, occupants have the potential for being partially ejected outside the window and then striking the LTV's hood.

b) *Proposed Initiatives*

Two side impact protection initiatives are being pursued. The first initiative is to upgrade FMVSS No. 214 to provide greater head and chest side impact protection. Testing and analysis to support an upgrade is being completed, and the agency expects to propose requirements late in 2003.

The second initiative is dependent upon the ability to establish an AHOF partner protection requirement. If an AHOF compatibility requirement appears to be feasible, the agency will investigate the desirability of modifying the FMVSS No. 214 static side door crush resistance test procedure to reflect such an AHOF requirement.

c) *Expected Program Outcomes*

The first desired outcome for self-protection would be to reduce the number of serious injuries and fatalities that result from head and chest impacts in side crashes. This would be achieved through the development of performance requirements to encourage the implementation of inflatable head impact protection and enhanced chest protection systems. The desired outcome from any modification of the side door crush resistance test procedure would be to reduce the number of serious injuries and fatalities that result from side impact crashes by improving the structural engagement between the striking and struck vehicles.

3) Lighting/Glare

a) *Highlights of Current Program*

Consumer complaints have risen sharply in the last several years about glare from headlamps. FMVSS No. 108, Lamps, Reflective Devices, and Associated Equipment," sets minimum and maximum performance levels for illumination. However, current headlamps vary considerably in performance for glare and illumination. The trade-off between good illumination performance and glare has been debated for a century.

The three major complaint areas are: 1) glare created by the high-mounted headlamps on LTVs, 2) glare from high intensity discharge headlamps (HIDs), and 3) glare from auxiliary lamps. Glare can be bothersome for drivers, particularly in the nighttime environment.

On September 28, 2001, NHTSA published a request for comments[22] on glare produced by lamps mounted on the front of vehicles, including upper and lower beam headlamps, and auxiliary lower beam headlamps. The agency has received over 4,000 comments on the notice, mostly from citizens urging us to "do something" to reduce glare. On February 12, 2003, NHTSA published another request for comments[23] on adaptive frontal-lighting systems, where the headlight system responds to its surroundings by customizing roadway illumination for the particular scenario.

b) *Proposed Initiatives*

NHTSA anticipates proposing amendments to FMVSS No. 108 within a year to address headlight mounting height and auxiliary lamps. Regarding HIDs, a research effort has been initiated to assess real world exposure of drivers to glare, including HIDs. Data will be collected and analyzed to determine what levels of glare drivers encounter, and appropriate next actions on HIDs.

c) *Expected Program Outcomes*

The desired outcome is to reduce excessive glare resulting in crashes while maintaining necessary road illumination and safety to prevent crashes.

4) Reform CAFE

In addition to implementing programs in support of its critical safety mission, NHTSA also has responsibility for the Corporate Average Fuel Economy (CAFE) program. The current structure of the CAFE system can provide an incentive to manufacturers to downweight vehicles, increase production of vehicle classes that are more susceptible to rollover crashes, and produce a less homogenous fleet mix. As a result, CAFE is critical to the vehicle compatibility and rollover problems.

a) *Highlights of Current Program*

In its final rule setting new CAFE standards for MY 2005-2007 light trucks,[24] NHTSA stated that it intends to examine possible reforms to the CAFE system, including those recommended in the National Academy of Sciences' CAFE report.[25]

b) *Proposed Initiatives*

Consistent with its statutory authority, the agency plans to address issues relating to the structure, operation and effects of potential changes to the CAFE system and CAFE standards. In taking this broad view, the agency recognizes that the regulation of the fuel economy can have substantial effects on vehicle safety, the composition of the light vehicle fleet, the economic well-being of the automobile industry and, of course, our nation’s energy security.

c) *Expected Program Outcomes*

It is NHTSA's goal to identify and implement reforms to the CAFE system that will facilitate improvements in fuel economy without compromising motor vehicle safety or American jobs. In 2003, NHTSA will issue an Advance Notice of Proposed Rulemaking (ANPRM) seeking comment on alternative approaches for reforming the structure of the CAFE program.

As NHTSA is, first and foremost, a safety agency, one of its core priorities will be to closely examine the safety consequences arising from the present composition of the light vehicle fleet. Armed with that information, NHTSA intends to examine the safety impacts, both positive and negative, that may result from any modifications to CAFE as it now exists. Regardless of the root causes, it is clear that the downsizing of vehicles that occurred during the first decade of the CAFE program had serious safety consequences. Changes to the existing system are likely to have equally significant impacts. NHTSA is determined to ensure that these impacts are positive.

B) Roadway Strategies

As shown in **Table 2**, over 3,300 fatalities from single-vehicle collisions with roadside hardware occurred in 2001, and increased diversity in the vehicle fleet will continue to make compatibility in these crashes an ever increasing challenge. FHWA has lead responsibility for compatibility initiatives relating to roadside hardware. According to the FHWA's *1998 National Strategic Plan*, roadside crashes cost society $80 billion each year. This is more than three times the annual amount spent by Federal, state, and local government agencies to maintain and operate the Nation's roads.

Changes in vehicle attributes over the past two decades, including size, mass, and geometry, have been considerable, while design criteria for roadside features have remained unchanged. The roadside features designed to perform optimally with older vehicles cannot be expected to perform adequately with current vehicles.

1) Improve Structural Engagement with Roadside Hardware

a) Highlights of Current Program

Through the FHWA/NHTSA National Crash Analysis Center (a federally funded research center concentrating on vehicle crash research), and the FHWA Centers of Excellence, a collection of finite element models (FEMs) has been developed to aid in the assessment and testing of roadside devices. These FEMs can be linked with vehicle crash models to determine the influence of various barrier and guardrail structural design parameters with vehicle attributes such as center of gravity location. Utilizing crash test information, the FEMs can be exercised to extrapolate test information to a broader range of vehicle designs, and identify roadside hardware designs that lead to better structural engagement with a broad range of vehicles.

b) Proposed Initiatives

FEM techniques will be utilized to determine the sensitivity of roadside hardware design parameters in establishing compatibility with a wide variety of vehicle characteristics. Design envelopes for roadside hardware will be defined to accommodate the wide variety of vehicles in the Nation's fleet. As NHTSA works to establish compatibility requirements applicable to vehicles, FHWA will exercise the FEMs to assess what effect potential countermeasures developed to meet these requirements would have on compatibility with roadside hardware.

NHTSA periodically reviews the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) information collection variables, and identifies changes and/or additional data that should be collected to strengthen the usefulness and predictive capability of the database. The NASS/CDS is a nationwide crash data collection program. It is operated by NHTSA's National Center for Statistics and Analysis (NCSA). NASS/CDS complements GES by collecting additional detailed information on a sample of police reported motor vehicle crashes occurring in the U.S. during the year involving passenger cars, light trucks and vans that were towed due to damage. FHWA and NHTSA will identify roadside hardware that would enhance vehicle compatibility with roadside hardware systems, determine the cost effectiveness of adding such variables, and prioritize the addition of further roadside hardware variables along with other variables under consideration for future modifications to the NASS/CDS database.

c) *Expected Program Outcomes*

The expected outcome will be to identify changes in roadside hardware design specifications to maximize proper vehicle structural engagement as the vehicle fleet changes.

2) Increase Awareness

a) *Highlights of Current Program*

FHWA does not establish regulations for the design of roadside hardware. Rather, state and local highway departments are responsible. FHWA works with States to identify and disseminate best practices.

b) *Proposed Initiatives*

FHWA efforts include initiatives to ensure that information regarding best practices for roadside hardware is more readily available at state and local highway departments. In order to improve the overall safety of vehicles entering the roadside, initiation of a cooperative approach between the roadside safety community and the automotive safety community will be explored. The creation of a working group within an existing professional society, such as the Society of Automotive Engineers (SAE), will be investigated. In addition, initiatives to increase automotive industry involvement in activities of the Transportation Research Board will be considered.

c) *Expected Program Outcomes*

The expected outcome would be an increased awareness of the importance of roadside hardware considerations within the roadside safety community.

C) Behavioral Strategies

1) Consumer Information Program

Market forces can have a very significant impact on automotive safety when consumers are given reliable information. NHTSA has received numerous comments from the public about a variety of compatibility issues, so the agency knows that this is a matter of concern to the public.

a) *Highlights of Current Program*

NHTSA is committed to using consumer information and performance results information to drive service and program improvements and to design programs and systems that focus on users. The agency has robust crash avoidance and crashworthiness information programs that are reflected in NCAP.

b) *Proposed Initiatives*

When NHTSA is able to develop metrics and requirements that reflect the compatibility of a particular vehicle, the agency will then investigate whether or not this would provide useful consumer information, and if so, how to best convey that information to the public so that they can utilize it in their purchasing decisions.

c) *Expected Program Outcomes*

NHTSA remains committed to providing consumers with helpful information to assist them in their motor vehicle buying decisions.

VI. Conclusion

Vehicle compatibility has been a concern for NHTSA since the 1970's. Recent sales and registrations of LTVs have steadily increased as a percentage of the passenger vehicle fleet, with LTVs representing 50 percent of new vehicle sales in 2001 and 37 percent of vehicle registrations. Consequently, this has led to an increased number of fatalities to car occupants who are struck by LTVs. This increase in passenger car fatalities has occurred even while the overall fatalities for the U.S. fleet has stabilized or decreased over the past several years. Therefore, NHTSA has made vehicle compatibility one of the agency's highest priorities and believes the initiatives included in this report will lead to both near-term and longer-term solutions to improve vehicle incompatibilities in the fleet.

REFERENCES

[1] "Overview of Vehicle Compatibility/LTV Issues," National Highway Traffic Safety Administration, February 1998.

[2] Chillon, "The Importance of Vehicle Aggressiveness in the Case of a Transversal Impact," Report on the First International Technical Conference on Experimental Safety Vehicles, Paris, January 1971.

[3] Kossar, Jerome M., "Big and Little Car Compatibility," Report on the Fifth International Technical Conference on Experimental Safety Vehicles, London, June 1974.

[4]Versace, John, "Safety Systems Optimization Model," Seventh International Technical Conference on Experimental Safety Vehicles," Paris, June 1979.

[5]"Five Year Plan for Motor Vehicle Safety and Fuel Economy and Invitation for Applications for Financial Assistance, National Highway Traffic Safety Administration, Docket No. 78-07, Notice 1, March 1978.

[6] MacLaughlin, T.F., Saul, R.A., and Daniel, S.; Causes and Measurement of Vehicle Aggressiveness in Frontal Collisions, Twenty-fourth Stapp Car Crash Conference, SAE Paper No. 801316, Troy, Michigan, October 15 - 17, 1980.

[7] MacLaughlin, T.F., Saul, R.A., and Morgan, R.M.; Vehicle Crashworthiness and Aggressiveness, VRTC Projects SRL-8 and SRL-9 Final Report, DOT HS 805-712 and DOT HS 805-713, January 1981.

[8]Saul, R.A., MacLaughlin, T.F., Ragland, C.L., Cohen, D.; Experimental Investigation of Crash Barriers for Measuring Vehicle Aggressiveness - Fixed Rigid Barrier Initial Results, SAE International Congress and Exposition, SAE Paper No. 810093, February 23 - 27, 1981.

[9] Michael W. Monk, Donald T. Willke; "Striking Vehicle Aggressivity Factors for Side Impact;" final report for project no. SRL-92; DOT-HS-806-917; January 1986.

[10] Michael W. Monk, Donald T. Willke; "Side Impact Aggressivity Attributes;" Tenth International Technical Conference on Experimental Safety Vehicles; July 1985.

[11]Gabler, Hampton C., Hollowell, William T., and Hitchcock, Ralph J., "Systems Optimization of Vehicle Crashworthiness," Fourteen International Technical Conference on the Enhanced Safety of Vehicles, Munich, May 1994.

[12]Gabler, Hampton C. and Hollowell, William T., "NHTSA's Vehicle Aggressivity and Compatibility Research Program," Sixteenth International Technical Conference on the Enhanced Safety of Vehicles, Paper No. 98-S3-O-01, Melbourne, Australia, June 1996.

[13] Gabler, Hampton C. and Hollowell, William T., "The Aggressivity of Light Trucks and Vans in Traffic Crashes," SAE Paper No. 980908, Detroit, March 1998.

[14] Gabler, Hampton C. and Hollowell, William T., "The Crash Compatibility of Cars and Light Trucks," Journal of Crash Prevention and Injury Control, Volume 2, Issue 1, pp.19-31, March 2000.

[15] *Automotive News Market Data Book*, Crain Communications, Inc. Detroit, MI. 1980-2001.

[16] National Vehicle Population Profile, R.L. Polk Company 1980-2001.

[17] Kahane, C., "Vehicle Weight, Fatality Risk, and Crash Compatibility," NHTSA publication. *To be published* in 2003.

[18] O'Reilly, Peter, "International Harmonised Research Activity (IHRA) – Vehicle Compatibility," 17th International ESV Conference, Amsterdam, The Netherlands, 2001.

[19] Hollowell, William T., Summers, Stephen M., and Prasad, Aloke, "NHTSA's Research Programme for Vehicle Aggressivity and Fleet Compatibility," C607/022/2002, UK ImechE Vehicle Safety 2002 Conference, London, May 2002.

[20] Samaha, Randa, "Side Impact Upgrade Research Update," NHTSA Research and Development Programs Public Meeting, July 2002.

[21] Samaha, Randa and Elliott, Daniel S., "NHTSA Side Impact Research: Motivation for Upgraded Test Procedures," 18th International Technical Conference on the Enhanced Safety of Vehicles, Nagoya, Japan, to be published, May 2003.

[22] 66 FR 49594

[23] 68 FR 7101

[24] 68 FR 16867, April 7, 2003.

[25] National Research Council, (January 2002). Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. Washington, DC; National Academy Press.